Non-destructive Identification of Woolly Peaches using Impact Response and Near-Infrared Spectroscopy

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A procedure which combines impact response and near-infrared sensing in a two-step classification method has been developed for identification of woolly peaches. Two hundred and seventy *Maycrest* peaches from three ripeness stages at harvest, stored during 0, 1, 2, 3 and 4 weeks at 1 and 5°C, were tested by non-destructive techniques (non-destructive impact and near-infrared spectroscopy) in order to assess woolliness (also known as mealiness in apples). Destructive mechanical tests (Magness–Taylor, confined compression and shear rupture) were used as a reference method to identify woolly fruits. Non-destructive impact data were processed by discriminant analysis to segregate into two texture categories (crispy–firm–hard and non-crispy–non-firm–soft). In the same way, discriminant analysis techniques were used to classify into three juicy categories (low juicy, medium juicy and high juicy), according to the near-infrared second derivative curve. Combining non-destructive impact and near-infrared spectroscopy, not crispy, not firm and soft fruit from the low juicy group were classified as woolly. The percentage of correctly classified fruits in both categories was 80%. The conditions about the experimental factors which enhance woolliness obtained from the destructive procedures were confirmed by the non-destructive procedure.

1. Introduction

Woolliness or leatheriness in peaches (mealiness in other fruits) is a negative attribute of sensory texture considered a physiological disorder associated with inadequate cold storage. It is characterized by the lack of crispness and juiciness without variation in the tissue water (Harket & Hallet, 1992). Although there is an external ripe appearance, the perception when consuming the fruit is not good due to the desegregated texture (Luza *et al.*, 1992) and to the lack of juiciness. Besides the lack of juiciness that characterize mealy textures, woolliness in peaches is associated with internal browning near the stone and the incapability of internal ripening, although there is an external ripe appearance (Kailasapathy & Melton, 1992).

On the basis of the information of a sensory panel of experts, destructive procedures to assess mealiness have been developed based on confined compression and shear rupture tests carried out with a universal testing machine (Barreiro *et al.*, 1998). When comparing mechanical and sensory appreciation of mealiness in apples, lack of crispness, of hardness and of juiciness were the major descriptors of the mealiness sensation. An expert sensory panel works with the average values from a batch and cannot be used as a reference for a fruit by fruit identification procedure.

Non-destructive procedures have also been attempted using nuclear magnetic resonance (Barreiro *et al.*, 1998). However, this technique is complex and not widely available at present. The development of simple and economical non-destructive methods to assess woolliness is required.

Non-destructive impacts enable the assessment of textural characteristics in pears and apples based on the deceleration–time curve (Jarén *et al.*, 1992). Chen and Ruiz-Altisent (1996) studied the optimal test conditions to assess firmness in pears with such impact device.

A lateral low-mass impact device has been developed to assess firmness in fruit for on-line applications (Chen & Tjan, 1998).

Near-infrared spectroscopy (NIR) is another non-destructive technique with high potential. Bellon-Maurel and Vigneau (1995) made a model to determine soluble solid content in apples in the range 800–1050 nm. Slaughter (1995) used visible and infrared spectroscopy to assess the internal quality of peaches and nectarines, measuring soluble solids, total sugar, sorbitol and chlorophyll contents. Lammertyn *et al.* (1998) assessed acidity, soluble solids and firmness in apples by non-destructive NIR procedures. This technique has also been used to assess juiciness in apples (Grummisch *et al.*, 1996).

Sensor fusion is a technique to estimate the characteristics of a bio-material by combining the information from different sensors. Steinmetz *et al.* (1996) developed a non-destructive sensor fusion system with three different sensing techniques, namely: sound, impact and micro-deformation in order to assess peach firmness. Sensor fusion is analogous to the cognitive process used by humans to integrate data continuously from their senses to make inferences about the surrounding world.

The objective of this study was to generate a non-destructive procedure to identify woolly peaches by combining impact and NIR sensors.

2. Material and methods

Early soft flesh peaches (cv. *Maycrest*) were used for this study. Peaches were grown in Murcia and split in samples within a factorial experimental design. These activities, which have been performed at the production area, were carried out by the Institute of Soil Science and Biology (CEBAS, CSIC, Murcia).

The experimental design can be summarized as:

(a) three different stages at harvest selected by production experts, within a set of fruits harvested on the same date in the same orchard, ripeness segregation being made mainly according to visual references (low, intermediate and high ripeness stage);
(b) two different storage temperatures tested under non-controlled atmosphere, + 1° and + 5°C; and
(c) five different storage periods tested, at harvest and weekly for a period of one month.

This design was adopted in order to achieve as wide a mealiness/woolliness range as possible. The total amount of fruits used for the experimental design was 270 (10 fruits per sample), five data were missed. The fruits were stored at CEBAS (Murcia) and sent to the laboratory in Madrid the night before the measurements were carried out. Isolated boxes with ice bags were used for transportation. All samples were weighed with a Bosch PE 620 balance, precision 0·1 g.

The tests carried out on these samples can be summarized as follows.

2.1. *Non-destructive tests*

2.1.1. *Near-infrared spectroscopy*

One spectra was taken in the blushed side of each peach (900–1400 nm, wavelength increment of 10 nm) with a spectrophotometer [Optical Spectrum Analyser 6602 from Monolight]. The light source consisted of a 12 V/100 W tungsten halogen lamp. The light was diffracted in a monochromator 6120, 900 line grating 1/mm and detector model 6112. With a bifurcated optical fibre, the light circulated from the light source to the fruit and from the fruit to the detector. The active area of the bifurcated fibre (4 mm diameter) was placed on the peach surface. A low-energy HeNe laser (type 2 a Bs 4803) and a spectrum from a $BaSO_4$ disc were used for calibration. Three silicone bases served as additional references. Infrared curves were processed to obtain 10 nm interval reflection relative data. First and second derivatives were calculated.

2.1.2. *Non-destructive impact response*

The non-destructive impact was carried out on the blushed side of each peach, where other mechanical parameters were also measured in a later stage. The impact test was made with an impact device developed by Chen *et al.* (1985). A 50 g instrumented steel rod with a spherical tip and a radius of curvature of 19·4 mm was dropped from a height of 4 cm onto each peach. The deceleration of the rod during impact was measured from the data given by an accelerometer connected to the end of the indentor. Impact curves were processed obtaining: maximum impact force (F_{max}) in N, maximum deformation (D_{max}) in mm, impact time duration (Dur) in ms, absorbed energy (E_{abs}) in J, maximum energy (E_{max}) in J and permanent deformation (D_{perm}) in mm.

2.2. *Destructive tests*

The equipment used for all mechanical tests was an universal mechanical test device to analyse food texture. It was connected to a computer which registers the curves and process the data.

2.2.1. *Magness–Taylor penetration test*

The Magness–Taylor flesh penetration test on whole fruits (without skin) was performed with a 8 mm diameter rod (0·5 cm^2). A maximum penetration of 8 mm was applied at 20 mm/min deformation rate. The maximum penetration force was registered and used as the Magness–Taylor firmness (MT) in N. One repetition was made per fruit.

2.2.2. *Confined compression test*

The confined compression test was carried out with the same universal mechanical testing device on cylindrical probes of 1·4 cm height and 1·4 cm diameter. Samples were confined in a disc of 1·4 cm height, with a hole of the same diameter as the probe. A maximum deformation of 2·0 mm was applied at a deformation rate of 20 mm/min. The rod used in this test has a 12·5 mm diameter in order to avoid rod/disc contacts during compression. Deformation was immediately removed at the same speed rate; one repetition was made per fruit. The following parameters were registered through this test: force/deformation ratio within the elastic behaviour, this magnitude being used as compression hardness (FD) in N/mm; and the area of the spot of juice, accumulated in a filter paper placed underneath the probe during the test, being used as compression juiciness (JA) in mm^2.

2.2.3. *Shear rupture test*

For this test a special device was developed in 1992 by Jaren and Ruiz-Altisent, comprising an 8 cm metacrilate cube, with a rectangular slot (3 cm long by 0·7 cm wide) through the centre. A sliding cutter, 3 cm wide by 9 cm long by 0·7 cm thick was inserted through this slot. Both the sliding cutter and the cube have a transversal cylindrical hole which are held in alignment at rest by spring tensioning the sliding cutter. A fruit sample was placed in the cylindrical hole and the rectangular cutter depressed to shear the sample. Two cylindrical nylon pieces joined together by a rubber band compress the sample to maintain it in a fixed position during the test. In this test, an increasing deformation was applied at a speed of 20 mm/min until the fruit sample rupture is achieved; one repetition was carried out per fruit. The maximum force at the shear rupture point was registered, and will be used as shear crispness (SF) in N (Paoletti *et al.*, 1993).

2.3. *Chemical tests*

The soluble solid content (SS) in Brix was measured with a digital refractometer from juice extracted from the blushed area of the fruit.

The titratable or total acidity using NaOH 0·1 N was carried out to an end point of pH 8·2 by a titration system, Titrator TR 85 and automatic burete T80 (Schott Gerate equipment) attached to a pH meter. The total acidity (AC) in meq/*l* was assessed from the same juice as soluble solids sample.

2.4. *Data analysis*

By Statistica 4·5 for windows, non-supervised clustering techniques and discriminant analysis (forward stepwise) are used to process the data.

A *k* means clustering was used to find the optimum 'partition' for dividing a number of objects into *k* groups. This procedure moves objects around from cluster to cluster in order to minimize the within-cluster variance and maximizing the between-cluster variance.

A stepwise discriminant analysis was used on a high number of parameters obtained in the study, in order to determine the ones that best discriminate between groups and to learn which measures offer the best prediction. The stepwise procedure is 'guided' by the *F to enter* value. The F value for a variable indicated its statistical significance in the discrimination between groups. The *F to enter* value determined how significant the contribution of a variable has to be in order to be added to the model. In the forward stepwise discriminant analysis the variables are chosen in the order of their contribution to the prediction. The variables were included in the model as long as the respective F values for those variables were larger than the *F to enter* (*F to enter* = 1·00) with a probability P lower than 0·05.

3. Results

In this study, a reference procedure has been compared to a new procedure. The reference method is based on a two-step identification pattern. In the same way, according to non-destructive measurements, the new procedure follows the same two-step pattern (*Fig. 1*). The first classification between crispy, firm and hard fruits (CH) and non-crispy, non-firm and soft fruits (S) is compared to the first classification into the same categories carried out according to the reference (Table 1). Then, inside the S category, the second classification into juicy categories is compared to the second classification carried out by the reference, also according to juiciness inside the S category (Table 2). In both procedures, the low juicy fruits from the S category are identified as woolly. Peaches identified as woolly by the new procedure are compared to those identified as woolly by the reference in each experimental group (Table 3); from this comparison the percentage of correctly classified fruits of the new non-destructive procedure is obtained, being 80%.

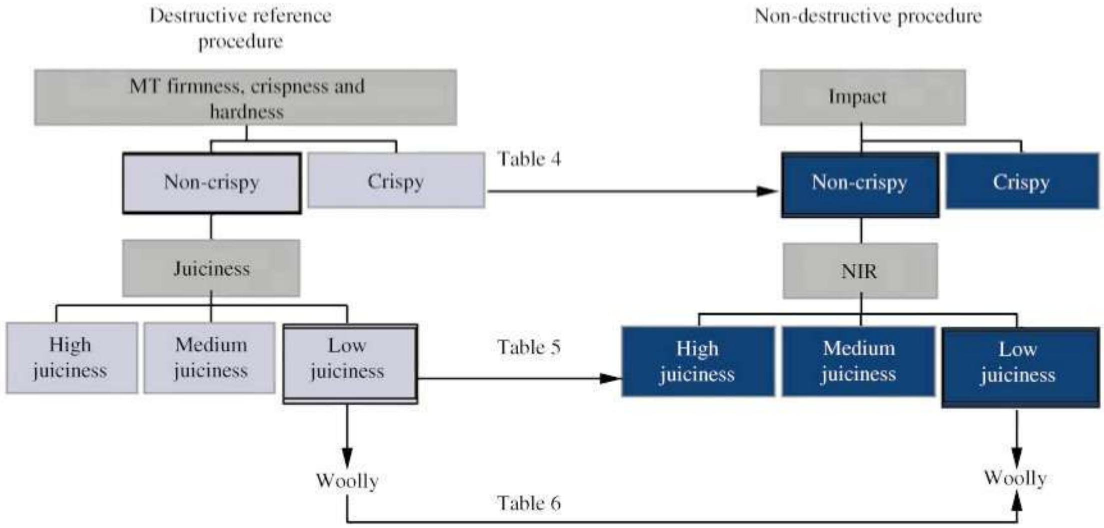

Fig. 1. Two-step classification pattern for the reference procedure and the non-destructive procedure: MT, Magness–Taylor firmness; NIR, near-infrared spectroscopy

3.1. *Woolly peach identification using the destructive reference procedure*

The identification of woolly peaches was carried out by the destructive procedure proposed by Ortiz *et al.* (1998). This method is based on a non-supervised classification technique, combining the instrumental measured variables of Magness–Taylor firmness in N, crispness in N, hardness in N/mm and juiciness in mm^2, obtained by the destructive tests, Magness–Taylor, shear rupture and confined compression. A first grouping is carried out according to the shear crispness, the Magness–Taylor firmness and the compression hardness by segregating two categories: crispy, firm and hard fruits (CH); and non-crispy, non-firm and soft fruits (S). In the second stage, fruits from S are classified into three juiciness categories according to their instrumental juiciness: high juiciness (HJ); medium juiciness (MJ); and low juiciness (LJ). Non-crispy, non-firm and soft fruits with low juiciness are identified as woolly fruits. This two-step classification provided a better identification of woolly peaches (*Fig. 1*, top left).

3.2. *Study of textural characteristics by non-destructive impact*

The impact variables, maximum force (F_{max}) and maximum deformation (D_{max}) show a significant correlation with the destructive parameters related to texture. The maximum force shows a correlation coefficient r of 0·81 for Magness–Taylor firmness and values for r of 0·64 for compression hardness and r of 0·75 for shear crispness, whereas the maximum deformation shows values for r of −0·71, −0·53 and −0·66 for the same variables, respectively (Table 4). However, F_{max} and D_{max} do not correlate with compression juiciness, correlation coefficients of 0·33 and −0·26, respectively.

Based on these results, F_{max} and D_{max} and the rest of the non-destructive impact variables were used to distinguish

Table 1
Classification matrix (crispy, firm and hard fruits (CH) and non-crispy, non-firm and soft fruits (S)); values in columns predicted by discriminant analysis based on the non-destructive impact variables

	Fruit categories with the non-destructive impact procedure			
Fruit categories with the reference procedure	*Fruits correctly classified, %*	*Crispy, firm, hard (CH)*	*Non-crispy, non-firm, soft (S)*	*Total*
Crispy, firm, hard (CH)	79·85	103	26	129
Non-crispy, non-firm, soft (S)	80·88	26	110	136
Total	80·38	129	36	

Table 2
Classification matrix; values in columns predicted by discriminant analysis based on the near infrared (NIR) spectroscopic variables; added in columns 5 and 6 are the mean and the standard error (SE) of the mechanical destructive parameter (compression juiciness in mm²) in the reference categories [high juiciness (HJ), medium juiciness (MJ) and low juiciness (LJ)]

Fruit categories with the reference procedure	*Fruit categories with the non-destructive impact procedure*				*Compression juiciness, mm²*	
	Fruits correctly classified, %	*High juiciness $P = 0{\cdot}18$*	*Medium juiciness $P = 0{\cdot}56$*	*Low juiciness $P = 0{\cdot}26$*	*Mean*	*SE*
High juiciness (HJ)	78·57	11	3	0	5·171	0·133
Medium juiciness (MJ)	73·85	10	48	7	3·183	0·032
Low juiciness (LJ)	60·00	4	14	39	1·802	0·050
Total	72·06	25	65	46		

P, probability.

between CH and S fruits. A 'forward stepwise' discriminant analysis selected five variables in the following order: F_{max}, D_{max}, Dur, E_{abs}, and D_{perm} (Tables 5 and 6).

The total percentage of well-classified fruits achieved with this procedure is 80·31% (no. of peaches $n = 265$): 79·85% ($n = 129$) in the CH group and 80·88% ($n = 136$) in the S group as compared to the reference (Table 1).

3.3. *Study of juiciness by NIR spectroscopy*

According to previous information on other fruits, NIR spectral curves and their derivatives were studied. Second derivatives in certain areas of the spectra presented significant but low correlation coefficients with compression juiciness, indicating that possible combinations of those NIR variables could be appropriate for juiciness segregation. In all cases, correlation coefficients of NIR variables with compression juiciness were higher than those found with mechanical or chemical parameters (Table 4).

Nine variables were selected by stepwise discriminant analysis in order to classify fruits in the three juiciness categories established with the destructive procedure: HJ, MJ, and LJ. These variables correspond to some second derivatives in the 900–1400 nm range, the range where water shows several absorbing bands. Table 2 shows the percentage of well-classified fruit for juiciness using the

Table 3
Non-destructive procedure errors classifying woolly peaches compared to the reference method, for the two storage temperatures, three ripeness stages and four periods of storage*

Storage duration, week	*Ripeness stage at harvest*	*Errors at storage temperature of 1°C*		*Errors at storage temperature of 5°C*	
		Over-detection errors	*Under-detection errors*	*Over-detection errors*	*Under-detection errors*
0	Low	0	0	0	0
	Medium	0	0	0	0
	High	0	0	0	0
1	Low	2	0	0	0
	Medium	1	0	3	0
	High	1	0	1	0
2	Low	0	0	0	0
	Medium	2	0	2	1
	High	2	0	3	2
3	Low	1	0	3	1
	Medium	2	0	0	2
	High	2	0	2	6
4	Low	2	1	2	0
	Medium	3	1	1	2
	High	1	1	0	1
Total		19	3	17	15

* Percentage of correctly classified fruits: 265-(19 + 3 + 17 + 15) = 211 → 211 × 100/265 = 80%.

Table 4

Correlation matrix between weight, soluble solid content (SS), total acidity (AC), compression juiciness (JA), Magness–Taylor firmness (MT), compression hardness (FD) and shear crispness (SF), with the non-destructive impact variables, maximum force (F_{max}), maximum deformation (D_{max}), permanent deformation (D_{perm}), absorbed energy (E_{abs}) and impact duration (Dur), and the second derivatives in certain wavelengths of the NIR spectra

Variables	*Weight, g*	*Soluble solid content, °Brix*	*Total acidity, meq/l*	*Compression juiciness, mm²*	*Magness–Taylor firmness, N*	*Compression hardness, N/mm*	*Shear rupture crispness, N*
Non-destructive impact							
Maximun force, N	0·20	0·02	0·63	0·33	0·81	0·64	0·75
Maximum deformation, mm	−0·15	0·01	−0·49	−0·26	−0·71	−0·53	−0·66
Permanent deformation, mm	0·58	0·21	0·01	−0·17	0·06	−0·05	0·07
Absorbed energy, J	0·10	−0·14	0.11	0·23	0·19	0·27	0·18
Impact duration, ms	−0·61	−0·22	−0·18	0·11	−0·29	−0·10	−0·28
NIR Spectroscopy							
Wavelength λ_1, nm	0·01	−0·09	0·31	0·42	0·17	0·20	0·19
Wavelength λ_2, nm	0·05	0·13	−0·23	−0·41	−0·14	−0·20	−0·12
Wavelength λ_3, nm	0·03	−0·13	0·36	0·41	0·32	0·26	0·29
Wavelength λ_4, nm	0·08	−0·20	0·27	0·5	0·21	0·23	0·25
Wavelength λ_5, nm	−0·09	0·19	−0·36	−0·56	−0·34	−0·27	−0·35
Wavelength λ_6, nm	0·01	0·22	−0·29	0·55	−0·17	−0·26	−0·18
Wavelength λ_7, nm	−0·04	−0·22	0·25	0·45	0·14	0·22	0·4

NIR procedure. Although the total percentage of well-classified fruit lies around 72·06% only four fruits (0·015%) were misclassified as high juicy when belonging to the low juiciness category and no fruits were misclassified as low juicy when belonging to the high juiciness category.

3.4. *Classification of woolly peaches combining both non-destructive methods*

The non-destructive procedure to identify woolly peaches is established on the basis of the referenced woolly fruit characteristics: fruits which are non-crispy, non-firm, soft and non-juicy. Peaches classified as S by non-destructive impact and simultaneously as LJ by NIR spectroscopy are identified as woolly peaches. When comparing the non-destructive classification to the destructive reference procedure, 80% of correctly classified fruits is found (211 over 265 fruits, taking into account individual cases).

In Table 3, non-destructive identification of woolly peaches is compared to the reference. Most misclassified peaches (erroneously identified as woolly) belong to peaches stored 2 weeks or more. There are two types of misclassification. A fruit can be classified as woolly by the destructive reference procedure and undetected by the non-destructive procedure, thus defined as an 'under-detection' error. On the other hand, a fruit can be classified as non-woolly by the destructive reference while it is

Table 5

Non-destructive impact variables used in the discriminant analysis [maximum force (F_{max}), maximum deformation (D_{max}), permanent deformation (D_{perm}), absorbed energy (E_{abs}) and impact duration (Dur)]; F to enter is the F value to enter or remove this variable in the function (this value has to be lower than the F value to enter this variable in discriminant function), P-value is the corresponding probability level for each F, and Lambda is the standard statistic that is used to denote the statistical significance of the discriminatory power of the current model (its value will range between 1, no discriminatory power, and 0, perfect discriminatory power)

	Step	*F to enter*	*P-level*	*Lambda*	*F value*
Maximum force, N	1	156·57	0·000	0·6268	156·57
Maximun deformation, mm	2	3·05	0·082	0·6196	80·42
Impact duration, ms	3	2·77	0·097	0·6131	54·90
Absorbed energy, J	4	1·28	0·258	0·6101	41·54
Permanent deformation, ms	5	1·83	0·177	0·6058	33·70

Table 6

Mean and standard error (SE) of the mechanical destructive parameters (MT, FD and SF) in the reference categories and of the impact variables maximum force and maximum deformation (F_{max} and D_{max}) for the same categories [crispy, firm and hard fruits (CH) and non-crispy, non-firm and soft fruits (S)]

		Crispy, firm, hard fruits (CH)	*Non-crispy, non-firm, soft fruits (S)*
Magness–Taylor firmness, N	Mean	36·28	18·72
	SE	0·62	0·75
Compression hardness, N/mm	Mean	50·67	19·23
	SE	1·28	1·11
Shear crispness, N	Mean	57·19	22·94
	SE	0·93	1·10
Maximum impact force, N	Mean	27·3	21·78
	SE	0·19	0·21
Maximum impact deformation, mm	Mean	2·38	2·50
	SE	0·01	0·01

identified as woolly by the non-destructive procedure: an 'over-detection' error. The number of over-detection errors obtained is higher than the number of under-detection errors. Most of the over-detection errors appear under 1°C conditions. The under-detection errors mainly appear at 5°C.

The features extracted on storage effects in previous studies, based on destructive techniques and sensory analysis (Ortiz *et al.*, 1998) are confirmed with the non-destructive classification procedure. Woolly peaches appeared after 2 weeks of storage at 5°C and did not appear at 1°C normal air storage, although they became very soft after 3–4 weeks, in *Maycrest* peaches.

4. Discussion

Peach textural characteristics (crispness, firmness, hardness and juiciness) have been assessed by a combination of two sensors: non-destructive impact and NIR spectroscopy. The correlation obtained between impact variables and the destructive mechanical parameters: shear crispness, Magness–Taylor firmness and compression hardness, show that impact parameters are able to assess those textural characteristics. A segregation between crispy–firm–hard fruits, and non-crispy–non-firm–soft fruits is obtained with more than 80% of well-classified fruits.

The non-destructive procedure for juiciness segregation based on NIR spectroscopy shows lower accuracy than non-destructive impact technique for texture assessment. This fact is assumed to be partly due to the lower reliability of the reference measurement of juiciness.

Figures 2 and *3* show the segregation of the two extreme textural categories (crispy–firm–hard *versus* woolly) for the destructive and non-destructive procedures, respectively. Slight differences in woolliness onset (border individuals) may be the cause for misclassification, although further study should be performed in this direction. This fact may be related to a higher number of 'over-detection' errors as the non-destructive method is more sensitive than the destructive method. Besides, experimental factor effect on the textural degradation is confirmed with the non-destructive procedure as: woolliness appeared after 2 weeks at 5°C. The developed non-destructive procedure to classify peaches according to their textural degradation stage is adequate to identify woolly peaches.

It is important to indicate that the non-destructive procedure has been developed based on a destructive

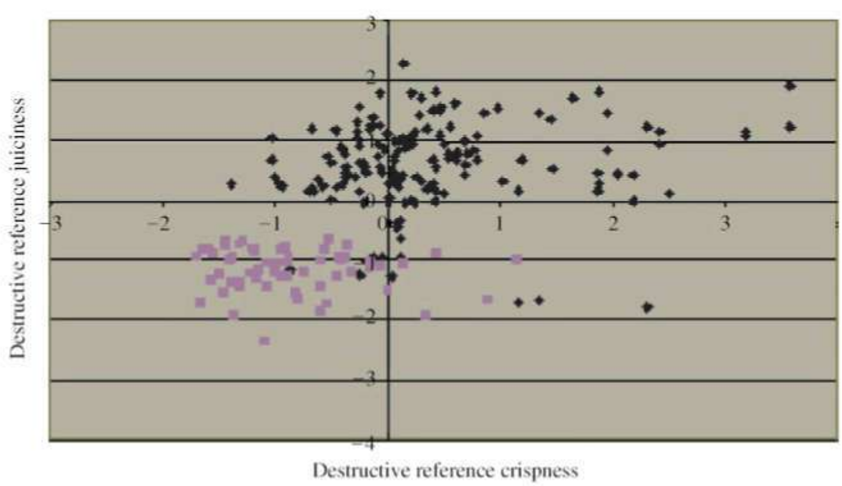

Fig. 2. Representation of the two extreme textural categories (crispy–firm–hard and woolly) according to the standardized destructive parameters (standardized destructive juiciness and standardized destructive crispness) for individual fruits values: ◆, crispy; ■, woolly

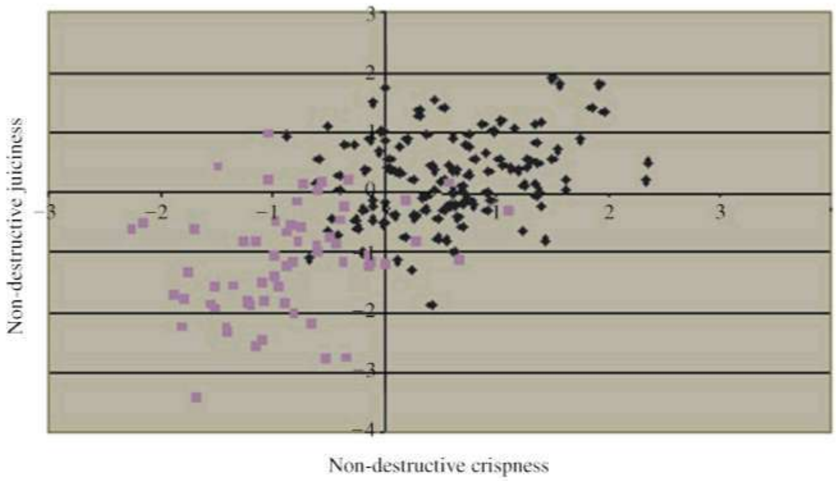

Fig. 3. Representation of the two extreme textural categories (crispy–firm–hard and woolly) according to the standardized non-destructive parameters (roots from the discriminant analysis) for individual fruit values; ◆, *crispy;* ■, *woolly*

procedure that may produce errors, when comparing it with the analysis of an expert sensory panel (Barreiro *et al*., 1998). Taking into account this problem, using the low-mass impact and the NIR sensors, a 80% of well-classified fruits is significantly high. A validation of the non-destructive procedure with the classification of an expert sensory panel is required, as well as reproducibility and stability studies, and feasibility in further peach varieties.

5. Conclusions

Non-destructive impact variables can be used to classify peaches according to the texture characteristics, crispness, firmness and hardness. However, this technique cannot be used to identify woolly peaches because non-destructive impact variables donnot give any information about the lack of juiciness that characterized woolly textures.

The near-infrared reflectance spectra gives certain information about fruit juiciness. The second derivative of the spectra can be used to classify peaches into juicy categories.

Combining non-destructive impact and near-infrared spectroscopy, a non-destructive procedure to identify woolly peaches can be established, with a percentage of well-classified fruits of 80%.

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